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The Historical and Current Status of Freshwater Fish in New South Wales

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ABSTRACT

Examples are given of a number of New South Wales freshwater fish species which have declined in abundance since last century. Reasons for the declines include river regulation, changes to riparian vegetation, erosion and siltation. The effects of alien species on the stocks of native fish are also discussed together with possible remedial measures to restore both habitat and fish communities.

INTRODUCTION

During the late 19th century and in the early part of this century Murray Cod *Maccullochella peelii peelii,* were abundant in the Murray-Darling River system. The explorer John Oxley (1820 in Rowland 1989) stated of the Lachlan River that "the river is rich in the most excellent fish, procurable in the utmost abundance. One man in less than an hour caught 18 large fish, one of which was a curiosity from its immense size and the beauty of its colours . . . it weighed an entire 70 pounds . . . Most of the other fish taken this evening weighed from 15 to 30 pounds." Conditions have changed dramatically in the intervening 174 years!

Concerns over the declining abundance of fish in New South Wales were raised as early as 1880 at the Royal Commission into the Fisheries of New South Wales. The trend of declining stocks of New South Wales freshwater fish species has been paralleled and indeed exacerbated by the degradation of fish habitats. Some examples and the probable causal mechanism are presented here together with an account of efforts to reverse the trend in stocks.

CONSERVATION STATUS OF NEW SOUTH WALES FRESHWATER FISHES

In New South Wales the freshwater fish fauna includes 83 species in 33 families including 12 alien species (14.5%) (Table 1). The numbers of some species have fallen to the extent that they have been listed as threatened. The Australian Society for Fish Biology has, since 1985, published a classification of Australian threatened fishes (Harris 1987; Jackson 1992; Wager and Jackson 1993 and Table 2) which presently includes 74 species (marine and freshwater). The increase from 59 to 74 species between 1985 to 1993 reflects an increase in awareness and knowledge of the subject, more than a dramatic deterioration, but the increase is nevertheless cause for concern.

Of the 71 New South Wales native species, 12 (16.9%) are included in the threatened species list (Table 3), with seven species in the categories of "Potentially Threatened" or "Endangered". No New South Wales species are listed as "Extinct" or "Vulnerable", although one species is of "Uncertain Status".

CASE HISTORIES OF REPRESENTATIVE SPECIES

1. Fish of the Coastal Drainage: Diadromous Fishes

a. Australian Bass *Macquaria novemaculeata*

Australian bass are representative of the nine catadromous species of coastal drainages, that is, migrating to the estuary for spawning and returning to fresh water as adults and juvenile fish. Bass spawn in the estuary in winter (optimal salinity 8–14 g l^{-1}) and the

Table 1. Regional representation of fishes in New South Wales fresh waters (dots indicate presence in region and * indicates alien species; † refers to species translocated from their normal range; sp1, sp2 refer to descriptions in McDowall 1980).

Family	Species	North coast	South coast	Murray system	Darling system
Ambassidae	*Ambassis agassizi*	●			
	Ambassis castelnaui			●	●
	Ambassis nigripinnis	●			
Anguillidae	*Anguilla australis*	●	●	●	
	Anguilla reinhardtii	●	●		
Apogonidae	*Glossamia aprion*	●			
Ariidae	*Arius graffei*	●			
Atherinidae	*Atherinosoma microstoma*	●			
	Craterocephalus amniculus				●
	Craterocephalus fluviatilis			●	
	Craterocephalus marjoriae	●			
	Craterocephalus stercusmuscarum	●			●
Belonidae	*Strongylura krefftii*	●			
Bovichthyidae	*Pseudaphritis urvillii*		●		
Chanidae	*Chanos chanos*	●			
Clupeidae	*Nematalosa erebi*	●		●	●
	Potamalosa richmondia	●	●		
Cobitidae	*Misgurnus anguillicaudatus**		●	●	
Cyprinidae	*Carassius auratus**	●	●	●	●
	*Cyprinus carpio**	●	●	●	●
	*Rutilus rutilus**			●	
	*Tinca tinca**			●	●
Eleotridae	*Butis butis*	●			
	Gobiomorphus australis	●	●		
	Gobiomorphus coxii	●	●		
	Hypseleotris compressa	●	●		
	Hypseleotris gallii				
	Hypseleotris klunzingeri	●		●	●
	Hypseleotris sp1			●	●
	Hypseleotris sp2	●		●	●
	Mogurnda adspersa	●		●	●
	Mogurnda mogurnda				●
	Philypnodon grandiceps	●	●	●	●
	Philypnodon sp1	●	●	●	●
Gadopsidae	*Gadopsis bispinosus*			●	
	Gadopsis marmoratus	●	●		●
Galaxiidae	*Galaxias brevipinnis*		●	●	
	Galaxias maculatus	●	●	●	
	Galaxias olidus	●	●	●	●
	Galaxias rostratus			●	●
Geotridae	*Geotria australis*			●	
Gobiidae	*Acanthogobius flavimanus**		●		
	Arenigobius bifrenatus	●	●		
	Pseudogobius olorum	●	●		
	Redigobius macrostoma	●	●		
Hemirhamphidae	*Arramphus sclerolepis*	●			
Kuhliidae	*Nannoperca australis*			●	
	Nannoperca oxleyana	●			
Lutjanidae	*Lutjanus argentimaculatus*	●			
Megalopidae	*Megalops cyprinoides*	●			
Melanotaeniidae	*Melanotaenia duboulayi*	●			
	Melanotaenia fluviatilis			●	●
	Pseudomugil signifer	●	●		
	Rhadinocentrus ornatus	●			
Monodactylidae	*Monodactylus argenteus*	●	●		
Mordaciidae	*Mordacia mordax*		●	●	
	Mordacia praecox		●		
Mugilidae	*Aldrichetta forsteri*		●		
	Liza argentea	●	●		
	Mugil cephalus	●	●		
	Myxus elongatus	●	●		
	Myxus petardi	●	●		
	Valamugil georgii	●	●		
Percichthyidae	*Maccullochella ikei*	●			
	M. macquariensis		●†	●	●
	M. peelii peelii		●†	●	●
	Macquaria ambigua	●†		●	●
	Macquaria australasica		●	●	●
	Macquaria colonorum	●	●		
	Macquaria novemaculeata	●	●		

Table 1 — continued

Family	Species	North coast	South coast	Murray system	Darling system
Percidae	*Perca fluviatilis**	●	●	●	●
Plotosidae	*Neosilurus argenteus*				●
	Neosilurus hyrtlii				●
	Tandanus tandanus	●	●	●	●
	Tandanus sp.	●			
Poeciliidae	*Gambusia holbrooki**	●	●	●	●
Prototroctidae	*Prototroctes maraena*		●		
Retropinnidae	*Retropinna semoni*	●	●	●	●
Salmonidae	*Oncorhynchus mykiss**	●	●	●	●
	*Salmo salar**		●	●	
	*Salmo trutta**	●	●	●	●
	*Salvelinus fontinalis**	●	●	●	
Scorpaenidae	*Notesthes robusta*	●	●		
Teraponidae	*Bidyanus bidyanus*	●†	●†	●	●
	Leiopotherapon unicolor	●			●

juveniles migrate to fresh water between January and May (Harris 1986). The catadromous spawning migration, and spawning behaviour itself, occur in response to flooding or smaller increases in streamflow. Because of this relationship, peaks in Australian bass recruitment, and subsequent cohort abundance, are strongly correlated with years of high river flows during July and August (Fig. 1) (Harris 1988). However, widespread river regulation by dams has suppressed the frequency of these high flows, reducing the rate of population recruitment in bass.

Table 2. Conservation status of threatened fish species in New South Wales. Numbers 1985 to 1993. Australian Society for Fish Biology (Jackson 1992).

	Year						
Classification	1993	1992	1991	1990	1989	1988	1985
Extinct	0	0	0	0	0	0	0
Endangered	11	11	9	8	6	5	4
Vulnerable	6	5	6	6	5	5	4
Potentially threatened	11	10	7	5	4	3	5
Indeterminate	3	2	2	2	2	2	2
Restricted	27	30	32	30	31	33	29
Uncertain status	16	14	13	13	16	16	15
Total	74	72	69	64	64	64	59

Table 3. Conservation status of threatened fish species in New South Wales.

Extinct	0
Endangered	*Maccullochella macquariensis* *Maccullochella ikei* *Nannoperca oxleyana*
Vulnerable	0
Potentially threatened	*Craterocephalus fluviatilis* *Mordacia praecox* *Prototroctes maraena* *Bidyanus bidyanus*
Indeterminate	*Macquaria australasica*
Restricted	*Craterocephalus amniculus* *Galaxias rostratus* *Mogurnda adspersa*
Uncertain status	*Tandanus* sp
Total	12

Artificial barriers, including weirs, dams and causeways have obstructed spawning and recruitment migrations in many coastal rivers, and access to approximately half of the total stream length potentially available has been obstructed by such barriers (Harris 1984). In some rivers, migration is only possible in those

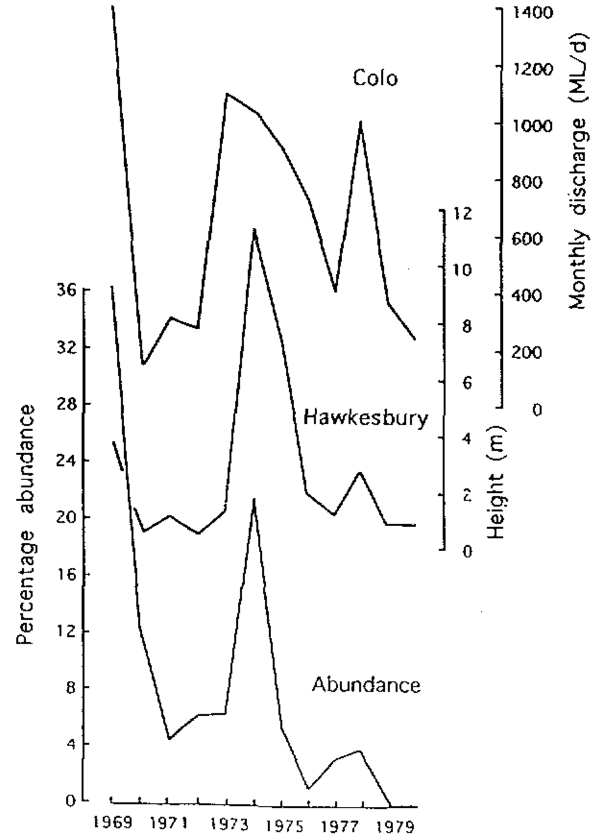


Figure 1. Relative initial year-class abundance of Hawkesbury Bass over a 12 year period. Percentage abundance is compared with average monthly discharge of the Colo River (Ml per day), and peak height (m) of the Hawkesbury at North Richmond, during July and August of the year of spawning (From Harris 1988).

years in which high flows drown-out barriers and, as a result, there are frequent gaps in the annual recruitment pattern.

Table 4. The numbers of impoundments obstructing fish passage (includes all types of dams and weirs) in large coastal rivers of New South Wales, plus the proportion of total stream length upstream of major impoundments (from Harris 1984).

River system	Number of impoundment	Per cent of valley length
Richmond	23	14
Clarence	7	11
Hunter	18	29
Hawkesbury	82	49
Shoalhaven	18	80
Snowy	9	16

The mean age and size of bass in the Hawkesbury River system (Fig. 2) decreased during a four-year study, despite a drought period when spawning was negligible (Harris 1988). The increased rate of total mortality causing the observed decline in age and size, was mainly attributed to fishing pressure.

The effects of artificial barriers apply similarly to some 26 diadromous fish species, that is all of those migrating between fresh water and the estuary/sea at some specific stage of their life-cycle, including the catadromous, anadromous and amphidromous groups (Harris 1984). These other affected species include Congolli *Pseudaphrites urvillii,* which appear to migrate downstream as adults to spawn in weedy estuaries from late April to August (Allen 1989), Freshwater Herring *Potomalosa richmondia,* Striped Mullet *Mugil cephalus* and Freshwater Mullet *Myxus petardi.*

b. Australian Grayling *Prototroctes maraena*

The Australian Grayling, a threatened species, is fecund (mean number of eggs 47 000) and lives for an estimated five years (Berra 1982, 1987). Spawning is thought to occur in fresh water, the larvae then being swept downstream to the estuary and juvenile fish migrating upstream four to six months later. Such a life-history is amphidromous, i.e., those diadromous fish which migrate regularly at a particular stage of their life-cycle but not for the purpose of spawning. The Australian Grayling had only one congener, the New Zealand Grayling *P. oxyrhynchus,* which is now extinct. Although several theories exist as to the causes of extinction including habitat degradation, disease and competition from alien species, McDowall (1989) considers that its extinction is not properly understood.

2. Non-diadromous Fishes of Coastal Drainages

a. Eastern Cod *Maccullochella ikei*

Until the early 1900s large populations of this now-endangered species existed in the Clarence and Richmond River systems of northern New South Wales. The Eastern Cod is a large, long-lived, slow-growing species with relatively low fecundity and a long generation period (Rowland 1993). In 1863 large numbers of fish up to 27 kg were caught in the Clarence River and its tributary, the Orara River. A dramatic decline in abundance occurred in the period to 1930, by which time the species was probably near extinction in the Richmond River (Rowland 1993). In the Richmond River the decline was associated with the construction of the north coast railway, which closely follows the river, and the extensive dynamiting which occurred. River flooding and siltation were also implicated, and the species disappeared from much of the Clarence River system after a number of flood-related fish-kills during the 1920s and 1930s. Again, the building of the railway was probably a contributory factor but poor land-use practices, especially those leading to catchment erosion and siltation, and damage to riparian vegetation corridors have also undoubtedly contributed to loss of habitat for the cod. Like the other three Australian freshwater cod species, Eastern Cod is highly vulnerable to fishing, and gross overfishing has been implicated in their declines. Regulatory controls, including a total ban in the catching of Eastern Cod, have been imposed to protect this species in New South Wales.

Small numbers of Eastern Cod were captured in the upper Clarence River, in pristine habitat, during the 1980s for a species-conservation project by New South Wales Fisheries. Techniques for artificial breeding were then developed at the Eastern Freshwater Fish Research Hatchery and 29 000 juvenile Eastern Cod were released into the Clarence and Richmond River systems, and their survival is being monitored.

3. Murray-Darling River Basin Species

a. Murray Cod *Maccullochella peelii*

The commercial fishery for Murray Cod declined from a peak in 1918. On the Murray River it is probable that, at lest until the 1930s

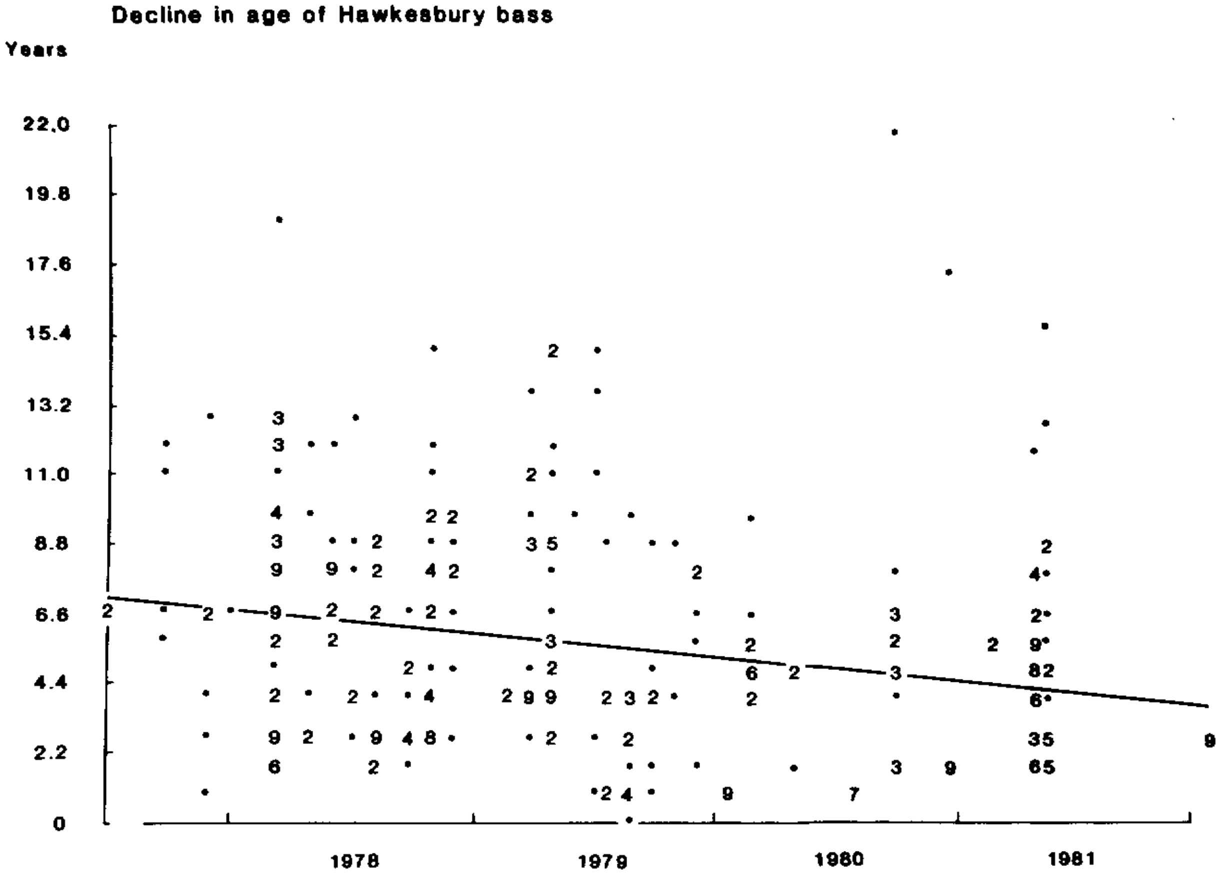
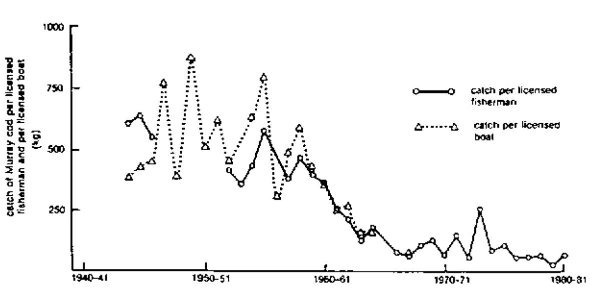


Figure 2. Ages of Bass taken in bass residential habitats of the Hawkesbury River system during the sampling period plotted against time. Where more than one data point falls in an individual plot area, the number is indicated by numerals (9 represents nine or more) (n = 386) (From Harris 1988).

and probably through recent years, the decline of the cod fishery was largely caused by overfishing by both commercial and recreational fisheries (Rowland 1989). Although the fishery was becoming uneconomic for large-scale operators by the 1930s, catches of Murray Cod in the period from 1940 to 1951 represented 42–65 per cent of the entire inland fishery (Figs 3 and 4). By 1955–56 the catch decreased further and today Murray Cod form only 10 per cent of the total freshwater commercial catch (Rowland 1988; New South Wales Fisheries Annual Reports). In 1928 there were 1 300 commercial fishermen on the Murray River/Riverina but by 1993 this number had fallen to only 48 in New South Wales (Grant 1993). Apart from over-exploitation by commercial and recreational fisheries, a decrease in spawning success due to river regulation and general habitat degradation has also reduced recruitment and survival of the Murray Cod. Fish larvae are dependent on the availability of zooplankton and other small aquatic organisms such as insect larvae for their early survival and growth. These prey become abundant on the floodplain following inundation during floods. But the frequency, timing and duration of floods has been considerably reduced by river regulation by dams, weirs and abstractions so that the regular spring floods no longer occur every year. Cod spawn in spring and early summer, and thus optimal conditions for the spawning of Murray Cod now occur less frequently than in the pre-regulation period (Rowland 1988).



(Source: annual reports, N.S.W. State Fisheries Department)

Figure 3. Total annual catch per licensed fisherman per licensed boat from inland waters in New South Wales from 1940 to 1981 (From Rowland 1989).

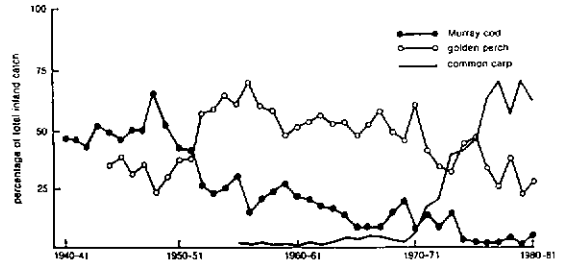
b. Silver Perch *Bidyanus bidyanus*

Silver Perch were once very common in most areas of the Murray-Darling River system but this species is now formally classified as "Potentially Threatened" (Jackson 1993). At Euston Weir on the Murray River historical data (Mallen-Cooper and Brand 1992) show that during the period 1941–42, Silver Perch were the most abundant fish to use the fishway. During that period, 11 526 Silver Perch were captured with up to 450 fish moving each day. In 1991 only 317 Silver Perch used the fishway and the maximum catch was 38 in a day (Mallen-Cooper and Brand 1992). The data indicated a decline in the mean annual abundance of Silver Perch of 93 per cent of this 50-year period (Mallen-Cooper 1993). Over the same period, the frequency of the small floods of 5 000–10 000 ml/day, which stimulate migration, have declined by about half (Close 1990; Mallen-Cooper 1992). Silver Perch are thought to be flood-spawners so reduction in the frequency of river flooding may lead to substantial reductions in recruitment success.

REASONS FOR THE DECLINE IN NATIVE FISH POPULATIONS

River Regulation

Not only the coastal species, but nearly all freshwater fish species in New South Wales need to migrate at some specific period in their life-cycle for breeding, recruitment processes and/or redistribution. The more obvious effect of dam and weir building is to physically prevent such movement. Less obvious effects of river regulation include the loss of environmental cues (such as surges in food abundance) for life-history events, inadequate flows for passage past obstacles, or excessive water velocities downstream of irrigation storages. Similarly, poor water quality because of hypolimnetic (i.e., from deeper layers of dams) releases of cold, deoxygenated water, often containing hydrogen sulphide and other toxic substances, and the modified flow regime, particularly related to changes to the seasonality of flows and temperature regime of the natural pattern are often associated with river regulation by dams.



(Source: annual reports, N.S.W. State Fisheries Department)

Figure 4. Percentage composition of Murray Cod (open circles), Golden Perch (solid circles) and Carp (solid line) in the commercial catch from inland waters in New South Wales from 1940 to 1981. Note that the dramatic increase in Carp occurred well after the decline of Murray Cod (From Rowland 1989). The earlier reports of Carp in commercial catches could possibly include some Goldfish *Carassius auratus*.

Water temperatures are usually severely depressed downstream of impoundments which release cold, hypolimnetic water (Pollard *et al.* 1980; Llewellyn 1983; Wager and Jackson 1993) (Fig. 9). This has a severe effect on fish distribution and spawning. In the Macquarie River below Burrendong Dam the effects of this have only recently begun to be investigated (Harris, NSW Fisheries, and Erskine, UNSW, pers. comm. 1994). It has been found that irrigation water released during spring and summer depresses water temperatures in the river by at least 10°C, and depressed water temperatures can be found downstream as far as the river reach between Dubbo and Warren (Swales 1994).

River regulation, water diversion and abstraction (Fig. 5), have caused the Murray River to become a series of connected pools with stable water levels. As a result the ecological processes in the river have been grossly altered (Walker and Thoms 1993). It has been estimated that two-thirds of the flow of the Murray River is diverted to supply irrigation water for agricultural land (Fig. 6). Together with this, floods are suppressed, and there is a phase shift (Fig. 7) in the seasonal flows and flood patterns (see section on Murray Cod). Further downstream, near the South Australian border, the phase shift disappears because of the extraction of irrigation supplies but flow volume and variability are reduced (Fig. 8).

Loss of Riparian Vegetation

The widespread loss or degradation of riparian vegetation in most New South Wales streams has many direct and indirect effects on fish. These effects are mostly related to the losses of shelter, or stream-bank stability and of the filtering effect of riparian buffer strips. Chief amongst these are the loss of preferred habitat for many native fish, associated with increased sunlight and temperature, increased algal growth, increased predation, reduction

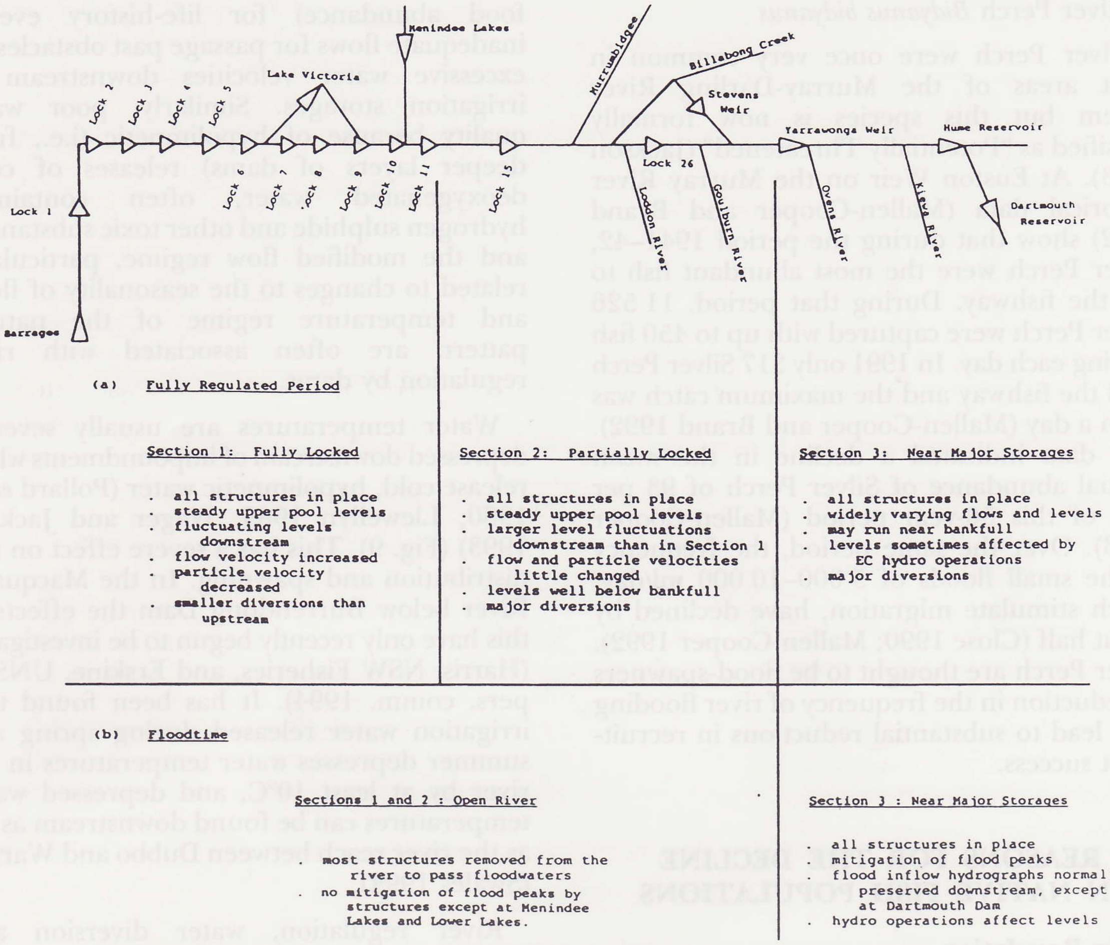

Menindee Lakes
Lake Victoria
Murrumbidgee
Billabong Creek
Stevens Weir
Yarrawonga Weir
Hume Reservoir
Dartmouth Reservoir
Lock 1
Lock 2
Lock 3
Lock 4
Lock 5
Lock 6
Lock 7
Lock 8
Lock 9
Lock 10
Lock 11
Lock 15
Lock 26
Loddon River
Goulburn River
Ovens River
Kiewa River
Barrages
(a) Fully Regulated Period
Section 1: Fully Locked
. all structures in place
. steady upper pool levels
. fluctuating levels downstream
. flow velocity increased
. particle velocity decreased
. smaller diversions than upstream
Section 2: Partially Locked
. all structures in place
. steady upper pool levels
. larger level fluctuations downstream than in Section 1
. flow and particle velocities little changed
. levels well below bankfull
. major diversions
Section 3: Near Major Storages
. all structures in place
. widely varying flows and levels
. may run near bankfull
. levels sometimes affected by EC hydro operations
. major diversions
(b) Floodtime
Sections 1 and 2 : Open River
. most structures removed from the river to pass floodwaters
. no mitigation of flood peaks by structures except at Menindee Lakes and Lower Lakes.
Section 3 : Near Major Storages
. all structures in place
. mitigation of flood peaks
. flood inflow hydrographs normally preserved downstream, except at Dartmouth Dam
. hydro operations affect levels

Figure 5. Summary of water level and flow behaviour of the Murray River (From Jacobs 1988).

in terrestrial food input and loss of spawning and nursery habitat (see Bunn *et al.* 1993).

Catchment erosion

Accelerated erosion of stream banks and river catchments has led to instream siltation and the loss of suitable substrates for spawning, shelter and food production. In most grazing areas stock (sheep and cattle) are allowed unlimited access to stream banks, increasing erosion of banks, siltation and nutrients (cattle numbers in Australia increased from 3.9 million in 1861 to 23.6 million in 1991, Castles 1993).

The previously widespread practice of desnagging submerged timber from the river, to increase flow and navigation, also destroys fish habitats by changing habitat structure and the flow characteristics of the river and reducing sites for shelter, food-production and spawning.

Alien Species

"Any and every fish introduction will result in changes to the native biota, often negative, and may not become manifest for decades" (Courtenay 1989). As noted earlier, 16.9 per cent of the New South Wales freshwater fish fauna is alien to Australia, having been introduced by people. These introductions have almost invariably caused adverse effects on native fish.

For example Carp *Cyprinus carpio* have been in Australia for over 100 years but it is only in the last 30 years that an illegal import of a new strain caused their spread throughout south-east Australia (Morison and Hume 1989). Although they have become abundant in many areas, a study of Victorian populations failed to prove that Carp caused environmental damage. Morison and Hume (1989) concluded that "the true extent of its undoubtedly deleterious effect on the aquatic environment remains open to speculation". New studies by the Co-operative Research Centre for Freshwater Ecology, CSIRO and New South Wales Fisheries Research Institute are being undertaken to clarify the ecological impacts of Carp, and their extent and distribution in New South Wales. Central to their possible ecological effects are the destruction of beds of aquatic

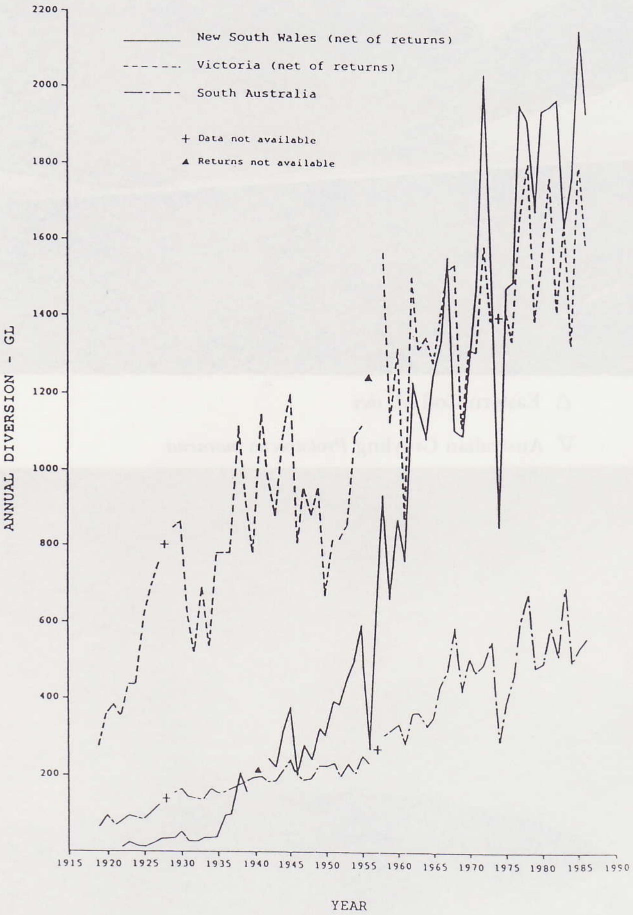


Figure 6. Trend in state diversions of water from the River Murray. Note the large increase of diversions after World War II and also that New South Wales is the largest user of water (From Jacobs 1990).

plants, marked increases in turbidity which appear related to Carp feeding behaviour, and re-suspension of nutrients associated with cyanobacterial blooms (Gehrke and Harris 1994).

Carp are now widespread and abundant throughout most of the Murray-Darling basin and in some coastal systems following their introduction in about 1970. In the New South Wales inland commercial fishery after 1970 the proportion of Carp in the commercial catch gradually increased until 1980–81, when they formed the majority of the catch (Fig. 4). Fish sampling in 1992 and 1993 using fyke-nets and panel-nets at sites in the that Carp comprised 98.3 per cent and 91.9 per cent respectively of the total catch (P. Gehrke, pers. comm.).

Gambusia *Gambusia holbrooki* (previously inaccurately titled "mosquito fish") have had profound effects on small aquatic fauna in many parts of the world. The species is very widely distributed in Australia and similar profound effects have been reported here (Lloyd 1989). Thirty-five fish species worldwide have declined in abundance or range as a result of introductions of Gambusia (Lloyd 1989).

Rowland (1989) suggested that it is possible that Redfin Perch *Perca fluviatilis,* introduced from Europe last century, have contributed to the decline of Murray Cod in the southern sections of the Murray-Darling basin. As Redfin Perch spawn in early spring, juveniles may prey on Murray Cod larvae, and possibly compete for food with them. Redfin Perch also carry the epizooitic haematopoietic necrosis (EHN) virus which is acutely virulent for a number of native fish species including the "Potentially Threatened" species, Macquarie Perch *Macquaria australasica.*

A major threat facing New South Wales waterways is Tilapia *Oreochromis mossambicus,* a noxious species which may expand its current range in central and southern Queensland and move into the Murray-Darling basin or coastal waters in northern New South

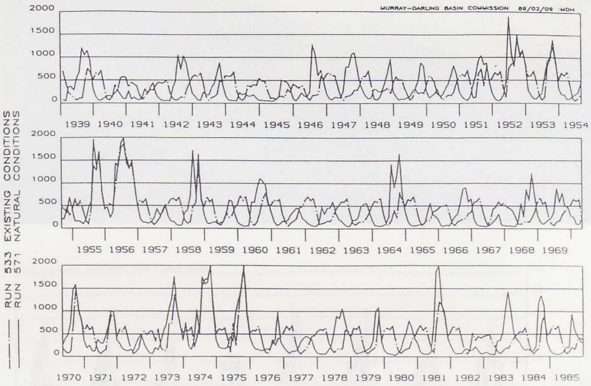


Figure 7. Flow at Albury. Natural (above Hume Dam, broken line) versus existing conditions (below the dam, solid line). Note the phase shift in seasonal flow patterns (From Jacobs 1988).

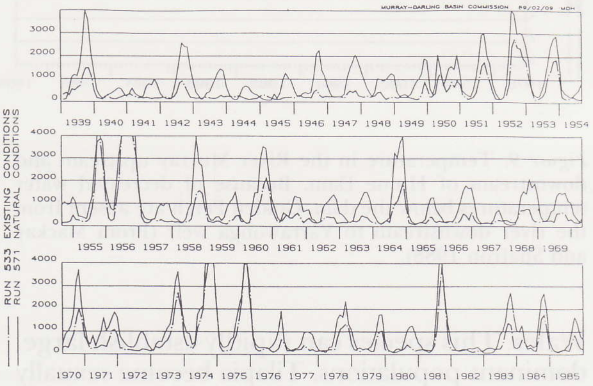
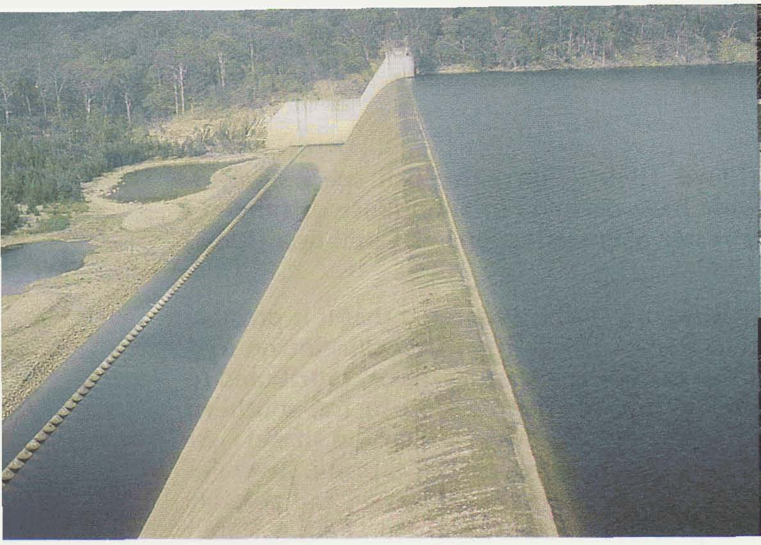


Figure 8. Flow at Euston — Natural versus existing patterns (GL/Mth). Note that at Euston the phase shift is no longer present because of diversions from the river during summer and the influx of floods from tributaries mainly in winter (From Jacobs 1988).

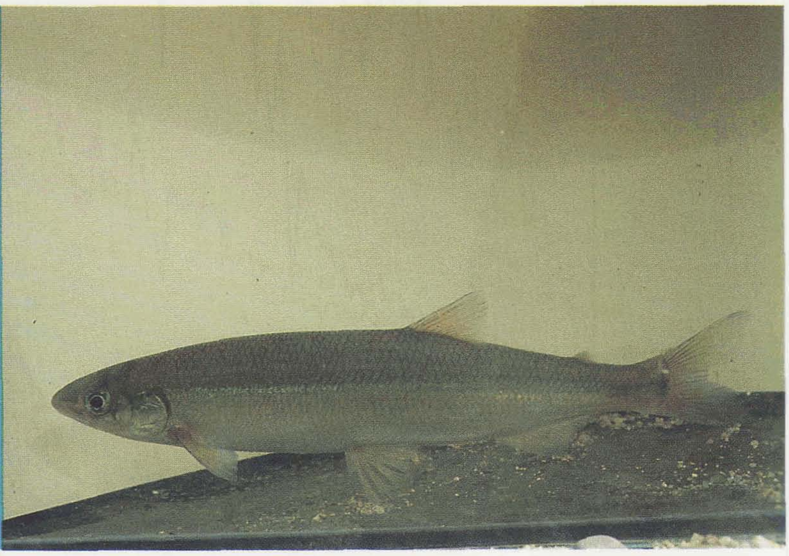


△ Tallowa Dam

△ Eastern Cod *M. ikei*

▽ Carp *Cyprinus carpio*

▽ Australian Greyling *Prototroctes maraena*



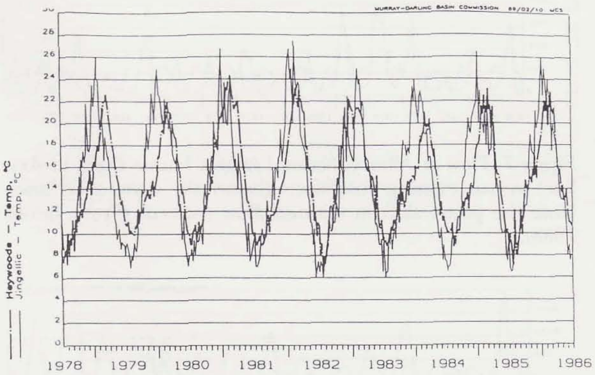


Figure 9. Temperature in the River Murray upstream and downstream of Hume Dam. Because of decreased water temperatures below the dam, Golden Perch are absent from the river downstream to Yarrawonga weir (From Mackay and Shafron 1988).

Wales. This species can rapidly establish large, dominant populations. Tilapia become sexually mature at 1–2 years old, grow to a maximum size of 350 mm, and can form stunted populations in nutrient-poor waters (Bluhdorn *et al.* 1990).

Trout, mainly Brown Trout *Salmo trutta* and Rainbow Trout *Oncorhynchus mykiss,* released late last century, quickly became established in suitable areas and have been implicated in eliminating some Australian native species such as galaxiids through competition and predation (Crowl *et al.* 1992; Tilzey 1976, 1977; Wager and Jackson 1993).

The impacts of other widely distributed alien species, especially Goldfish *Carassius auratus*, are not known but may contribute to the general decline of native fish in New South Wales.

REMEDIES

The causes of the decline in fish abundance and distribution are varied and often poorly documented (Mallen-Cooper 1993) but research into fish habitat restoration (Swales 1993) has started to redress some of the problems, in particular that of fish passage.

Fishways

Fishways installed to aid fish attempting to migrate apast artificial barriers in New South

Wales rivers were designed, before 1985, on European or North American models. Although suitable for salmonids, they were largely unsuitable for native species (Mallen-Cooper 1993). In recent years better fishways, especially the vertical-slot fishway design, have been installed at locations on the Nepean, Crawford, Murray and MacIntyre Rivers, on weirs less than 6.5 m high. The fishway at Torrumbarry on the Murray River, monitored since 1991, has so far been used by 14 000 fish, including all sizes and species of migrating native fish. Currently, some of the original ineffective fishways are being modified to improve fish passage by fitting prefabricated inserts of improved fishway designs. Several other modified designs have been installed on existing weirs. A recent experimental system for fish passage over low-level weirs (up to about 1 m high) involves a relatively low-cost solution, the rock-ramp fishway, in which a ramp of rocks is built from the weir crest downstream in a pool-riffle combination at a slope of 1:20. Several of these are being built and evaluated around New South Wales. Another recently approved type of fishway is the fishlock installed at Yarrawonga Weir which is designed to provide fish passage over a higher weir (10 m or more).

Restoring Fish Species and Communities

River rehabilitation and catchment improvement work have recently begun in New South Wales. This work includes limiting desnagging operations in many rivers which remove submerged logs, important as breeding and shelter sites. Education of land-users to limit access to the river by livestock which cause erosion and siltation in the rivers is also ongoing. Research activities currently underway in New South Wales Fisheries include studies of the distribution and abundance of fish species, including threatened species (Eastern Cod, Trout Cod, and Grayling). The development of successful breeding techniques for both Trout Cod and Eastern Cod has enabled re-establishment of populations of these species in suitable areas. A major study commencing in 1994, will study the fish resources of New South Wales rivers to better understand the health of the rivers. The study will examine the status of fish resources, the effects of Carp and other alien species, and the ecological effects of river regulation. It will also establish and test a standardized predictive model for monitoring river health using fish community assessments.

THE FUTURE

Depending on the cause of declining abundance of the fish communities in each river system, separate strategies are necessary for re-establishment. Research on restoring habitat has begun in several areas. There is greatly increased emphasis on the need for suitable environmental flows in rivers, and fish passage around and over barriers has improved considerably allowing fish to greatly extend their available habitat. Fishway designs are potentially available to allow fish over high level dams and it remains to establish the benefit in each case to justify the large construction costs. Similarly, eradication of alien species has been attempted at specific sites and although often unsuccessful in achieving total eradication (Burchmore *et al.*) can be of local benefit. Biological control methods are feasible for control of even large-scale invasions (such as Carp) but a potential for significant community benefit must first be demonstrated (Harris 1994) as such methods are both costly and require considerable trial and development times.

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REFERENCES

Allen, G. R., 1989. *Freshwater fishes of Australia.* T.F.H. Publications, 240 pp.

Berra, T. M., 1987. Speculations on the evolution of life history tactics of the Australian grayling. *Amer. Fish. Symp.* **1:** 519–30.

Berra, T. M., 1982. Life history of the Australian grayling *Prototroctes maraena* (Salmoniformes: Prototroctidae) in the Tambo River, Victoria. *Copeia* **1982:** 795–805.

Bluhdorn, D. R., Arthington, A. H. and Mather, P. B., 1990. The introduced cichlid *Oreochromis mossambicus* in Australia: A review of distribution, population genetics, ecology, management issues and research priorities. Pp. 83–92 in *Introduced and Translocated Fishes and their Ecological Effects* ed by D. A. Pollard. *Proceedings No. 8 Bureau of Rural Resources.* Bureau of Rural Resources: Canberra.

Bunn, S. E. Pusey, B. J. and Price, P., 1993. Ecology and management of riparian zones in Australia. *Land and Water Resources Occasional Paper No. 05/93.* Land and Water Resources Research and Development Corporation: Canberra.

Burchmore, J., Faragher, R. and Thorncraft, G., 1989. Occurrence of the introduced weather loach *(Misgurnus anguillicaudatus)* in the Wingecarribee River, New South Wales. Pp. 38–46 in *Introduced and Translocated Fishes and their Ecological Effects* ed by D. A. Pollard. *Proceedings No. 8 Bureau of Rural Resources.* Bureau of Rural Resources: Canberra.

Castles, I., 1993. *Year book Australia 1994.* Australian Bureau of Statistics: Canberra.

Close, A., 1990. The impact of man on the natural flow regime. Pp. 61–74 in *The Murray.* Murray-Darling Basin Commission.

Courtenay, W. R., 1989. Fish conservation and the enigma of introduced species. Pp. 11–20 in *Introduced and translocated fishes and their ecological effects* ed by D. A. Pollard. *Proceedings No. 8 of Rural Resources.* Bureau of Rural Resources: Canberra.

Crowl, T. A., Townsend, C. R. and McIntosh, A. R., 1992. The impact of introduced brown and rainbow trout on native fish: the case of Australasia. *Reviews in Fish Biology and Fisheries* **2:** 217–41.

Gehrke, P. C. and Harris, J. H., 1994. The role of fish in cyanobacterial blooms in Australia. *Aust. J. Mar. Freshwa. Res.* **45:** in press.

Grant, T. R., 1993. The past and present freshwater fishery in New South Wales and the distribution and status of the platypus *Ornithorhynchus anatinus. Aust. Zool.* **29:** 105–13.

Harris, J. H., 1984. Impoundment of coastal drainages of southeastern Australia, and a review of its relevance to fish migrations. *Aust. Zool.* **21**(3): 235–50.

Harris, J. H., 1986. Reproduction of the Australian bass *Macquarie novemaculeata* (Perciformes: Percichthyidae) in the Sydney Basin. *Aust. J. Mar. Freshwa. Res.* **37:** 209–35.

Harris, J. H. (ed), 1987. *Proceedings of the Conference on Australian Threatened Fishes.* Australian Society for Fish Biology, Melbourne, 15–16 August, 1985. Division of Fisheries, New South Wales Department of Agriculture: Sydney.

Harris, J. H., 1988. Demography of Australian bass, *Macquaria novemaculeata* (Perciformes, Percichthyidae), in the Sydney Basin. *Aust. J. Mar. Freshwa. Res.* **39:** 355–69.

Harris, J. H., 1994. Carp in Australia — the role of research. *Proceedings of the Forum on European Carp.* Published by Murrumbidgee Catchment Management Committee. Pp. 17–20.

Jackson, P., 1992. Australian Threatened Fishes — 1993 Supplement. *Aust. Soc. for Fish Biol. Newsl.* December 1992.

Jacobs, T. A., 1988. Regulation of the Murray-Darling River system. Pp. 55–96 in *Proceedings of the Workshop on Native Fish Management.* Murray-Darling Basin Commission.

Jacobs, T. A., 1990. River regulation. Pp. 39–58 in *The Murray.* Murray-Darling Basin Commission.

Llewellyn, L. C., 1983. The distribution of fish in New South Wales. *Australian Society for Fish Biology Special Publication* No. 7.

Lloyd, L., 1989. Ecological interactions of *Gambusia holbrooki* with Australian native fishes. Pp. 94–97 in *Introduced and Translocated Fishes and their Ecological Effects* ed by D. A. Pollard. *Bureau of Rural Resources Proceedings No. 8.* Bureau of Rural Resources: Canberra.

Mackay, N. J. and Shafron, M., 1988. Water quality. Pp. 137–47 in *Proceedings of the Workshop on Native Fish Management.* Murray-Darling Basin Commission.

Mallen-Cooper, M. and Brand, D., 1992. Assessment of two fishways in the River Murray and historical changes in fish movement. Unpublished Report, New South Wales Fisheries, Fisheries Research Institute: Cronulla.

Mallen-Cooper, M., 1993. Habitat changes and declines of freshwater fish in Australia: what is the evidence and do we need more? Pp. 118–23 in *Sustaining Fisheries through Sustaining Fish Habitat* ed by D. A. Hancock. Australian Society for Fish Biology Workshop. Bureau of Rural Resources Proceedings.

McDowall, R. M., 1989. Filling in the gaps — the introduction of exotic species into New Zealand. Pp. 69–82 in *Introduced and Translocated Fishes and their Ecological Effects* ed by D. A. Pollard. *Bureau of Rural Resources Proceedings No. 8.* Bureau of Rural Resources: Canberra.

McDowall, R. M. (ed), 1980. *Freshwater Fishes of Southeastern Australia.* Reed: Sydney.

Morison, A. and Hume, D., 1989. Carp (*Cyprinus carpio* L.) in Australia. Pp. 110–13 in *Introduced and Translocated Fishes and their Ecological Effects* ed by D. A. Pollard. *Bureau of Rural Resources Proceedings No. 8.* Bureau of Rural Resources: Canberra.

Pollard, D. A., Llewellyn, L. C. and Tilzey, R. D. J., 1980. Management of freshwater fish and fisheries. Pp. 227–70 in *An Ecological Basis for Water Resource Management* ed by W. D. Williams. ANU Press: Canberra.

Rowland, S., 1988. Murray cod. *Agfact* F3.2.4. New South Wales Agriculture and Fisheries.

Rowland, S. J., 1989. Aspects of the history and fishery of the Murray cod *Maccullochella peelii* (Mitchell) (Percichthyidae). *Proc. Linn. Soc. NSW* **111**(3): 201–13.

Rowland, S. J., 1993. *Maccullochella ikei,* an endangered species of freshwater cod (Pisces: Percichthyidae) from the Clarence River system, New South Wales and *M. peelii mariensis,* a new subspecies from the Mary River system, Queensland. *Rec. Aust. Mus.* **45:** 121–45.

Swales, S., 1993. Rehabilitation, mitigation and restoration of fish habitat in regulated rivers. Pp. 49–57 in *Sustaining Fisheries through Sustaining Fish Habitat* ed by D. A. Hancock. Australian Society for Fish Biology Workshop. Bureau of Rural Resources Proceedings.

Swales, S., 1994. Fish communities within the Macquarie River. *Proceedings of papers presented at the Macquarie River Workshop,* March 1994. Department of Water Resources.

Tilzey, R. D. J., 1976. Observations on interactions between indigenous Galaxiidae and introduced Salmonidae in the Lake Eucumbene catchment, New South Wales. *Aust. J. Mar. Freshwa. Res.* **25:** 551–64.

Tilzey, R. D. J., 1977. The key factors in the establishment and success of trout in Australia. *Proc. Ecol. Soc. Aust.* **10:** 97–105.

Wager, R. and Jackson, P., 1993. *The Action Plan for Australian Fishes.* Australian Nature Conservation Agency: Canberra.

Walker, K. F. and Thomas, M. C., 1993. Environmental effects of flow regulation on the lower River Murray, Australia. *Regulated Rivers: Research and Management* **8:** 103–19.